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TELEVISION RECEPTION OVER SEA PATHS: the effect of polarisation

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Summary

Fading of u.h.f. signals on oversea paths within the horizon can occur because of interference between the direct and sea-reflected signals. Comparisons of transmissions using horizontal polarisation (h.p.) and vertical polarisation (v.p.) have been made on short paths affected by fading. The results indicate that unacceptable fading can occur on either polarisation, although fading on v.p. is generally less serious.

Details are also given of a system using elliptical polarisation to reject the sea-reflected signals, which is expected to offer a considerable improvement over h.p. or v.p.

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TELEVISION RECEPTION OVER SEA PATHS: THE EFFECT OF POLARISATION

P.A. Laven

1. Introduction

Severe fading of u.h.f. signals on oversea paths has been observed in various parts of the U.K.[1] The fading is due to interference between the direct and sea-reflected components of the received signal. The relative phase alters as the level of the sea varies with the tide, the amplitude of the received signal changes and this can cause severe degradation of u.h.f. television reception.

In an earlier series of tests,[1] it was concluded that it would be advantageous to use vertical polarisation (v.p.) rather than horizontal polarisation (h.p.). To determine the effects of polarisation on short oversea paths, tests have been made from the Rosneath transmitting station. Most of the Rosneath u.h.f. service area will be exposed to sea

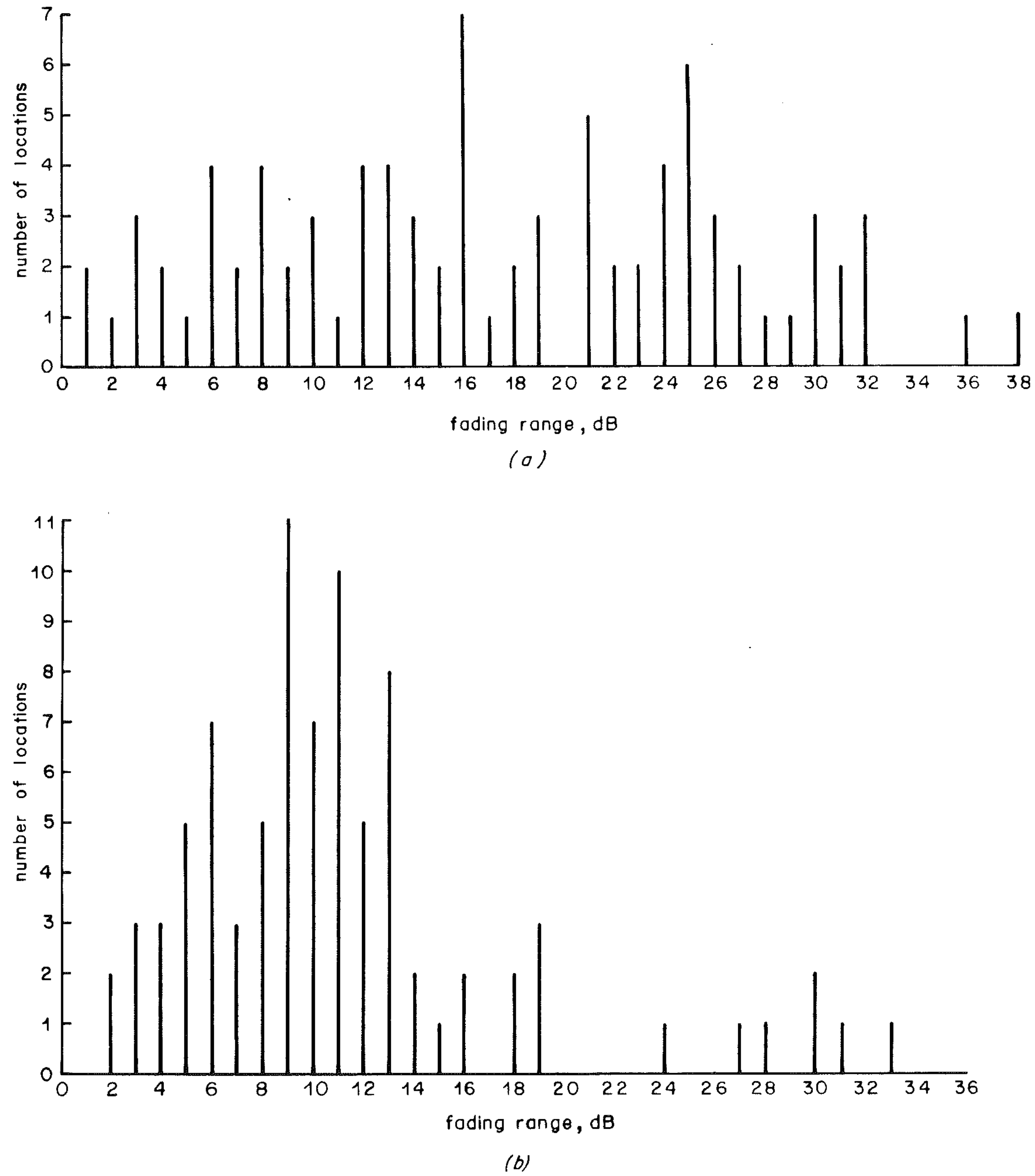

Fig. 1 - Measured fading ranges (maximum/minimum)
(*a*) Horizontal polarisation (*b*) Vertical polarisation

reflections and thus fading is an important factor in determining the service area.

2. Horizontal and vertical polarisations: tests in the Rosneath service area

2.1. Measurement techniques

Two c.w. test transmitters were mounted on the Rosneath mast: one on h.p. on 666 MHz and the other on v.p. on 756 MHz. Continuous recordings of field strength were made during half-tide cycles (about 6¼ hours) at a number of locations in the Dunoon, Gourock and Port Glasgow areas. To supplement these measurements, field strength recordings were made as the receiving aerial height was reduced from 10 m to 2·8 m above ground level – this procedure was repeated at various states of the tide and by comparison of the recordings the fading range (maximum/minimum) for each location was derived. The latter method enables measurements to be taken more quickly and the results are similar to those obtained by continuous recordings over a half-tide cycle.

2.2. Results and discussion of results

Figs. 1(*a*) and (*b*) show the distribution of the measured fading ranges for h.p. and v.p. respectively. The median fading range was 15·5 dB for h.p. and 9·5 dB for v.p. Fading ranges of >10 dB were recorded at 72% of locations for h.p. and 46% of locations for v.p. Similarly, the percentage of locations affected by fading ranges of >20 dB was 41% for h.p. and 8% for v.p.

Figs. 2(*a*) and (*b*) show the theoretical variation of reflection coefficients (ρ) of sea water with grazing angle for both polarisations, and the individual values of the effective reflection coefficient* (ρ_{eff}) derived from the measurements. For v.p. the individual values of ρ_{eff} are spread around for theoretical curve, but for h.p. the values tend to be lower than theoretical. The discrepancies are due mainly to signals reflected by the ground near the receiving location. The effects of such ground reflected signals depend on the relative phase of the direct and ground-reflected components; if they are in phase, the fading caused by the variable-phase sea reflected component will be reduced; if they are out of phase, the fading will be increased.

Diffuse reflection from the sea is caused by irregularities on the surface of the sea. As these irregularities move, the amplitude and phase of the reflected signal changes causing a change in field strength.[2,3] Amplitude variations of more than 20 dB at a frequency of about 0·3 Hz were observed during these tests.

These fluctuations cause variations of the chrominance-luminance and vision-sound ratios of a television transmission. The tests at Rosneath used c.w. transmissions and thus no information was obtained about the subjective effects of such variations on television reception. A laboratory simulation of these variations using colour television receivers has been made and the results show that the subjective effects depend on a number of factors: the most important being the type of television receiver, the amplitude of the received signal, and the amplitude end frequency of the fluctuations.

During earlier tests at the Wenvoe[1] transmitting station the effects of diffuse reflections were less important because of two main factors:

(a) The measurements were made during fine weather when the sea was calm, and thus the amplitudes of the diffuse components were low (during the Rosneath tests, poor weather conditions caused rough seas and thus the amplitudes of the diffuse components were greater).

(b) It can be shown that for a given value of surface roughness the amplitude of the diffuse component increases as the grazing angle ψ increases. For the Wenvoe transmissions across the Bristol Channel ψ is 1° or less; at Rosneath ψ can be as high as 4·5°, thus the diffuse component is more important at Rosneath.

It is probable that on short oversea paths, where ψ is large, the effects of the diffuse component on television reception may be more important than other types of picture degradation previously observed during tidal fading.

3. Elliptical polarisation

3.1. Theoretical considerations

For reflection from a plane surface, the incident and reflected waves differ in amplitude and phase as determined by the reflection coefficient. If the plane of polarisation of the incident wave is either parallel or perpendicular to the reflecting surface (h.p. or v.p. in the case of reflection at the surface of the sea) the reflected wave will have the same polarisation as the incident wave. For more complex polarisations, which can all be resolved into h.p. and v.p. components, the polarisations of the incident and reflected waves will be identical if the reflection coefficients for h.p. and v.p. are equal. When these reflection coefficients are unequal, the amplitude and phase relationships of the h.p. and v.p. components change, thus altering the polarisation of the reflected wave.

If the polarisations of the incident and reflected waves are different it is possible to reject one of the components by using the polarisation discrimination of the receiving aerial. If the polarisation of the incident wave is chosen so that the reflected wave is linearly polarised, a standard receiving aerial will reject the reflected wave if it is tilted at 90° to the plane of polarisation of the reflected wave. Since the receiving aerial tilt required to reject the reflected

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* The reflection coefficient is the ratio between the amplitudes of the direct and the sea-reflected components. In practice the direct component is often modified by other components of constant phase, such as ground reflected signals. The fading range is determined by the relative amplitudes of the constant phase components (i.e. direct and ground reflections) and the variable phase components (i.e. sea reflections): hence the use of the term 'effective reflection coefficient' which implies the ratio between the amplitudes of the constant and variable components.

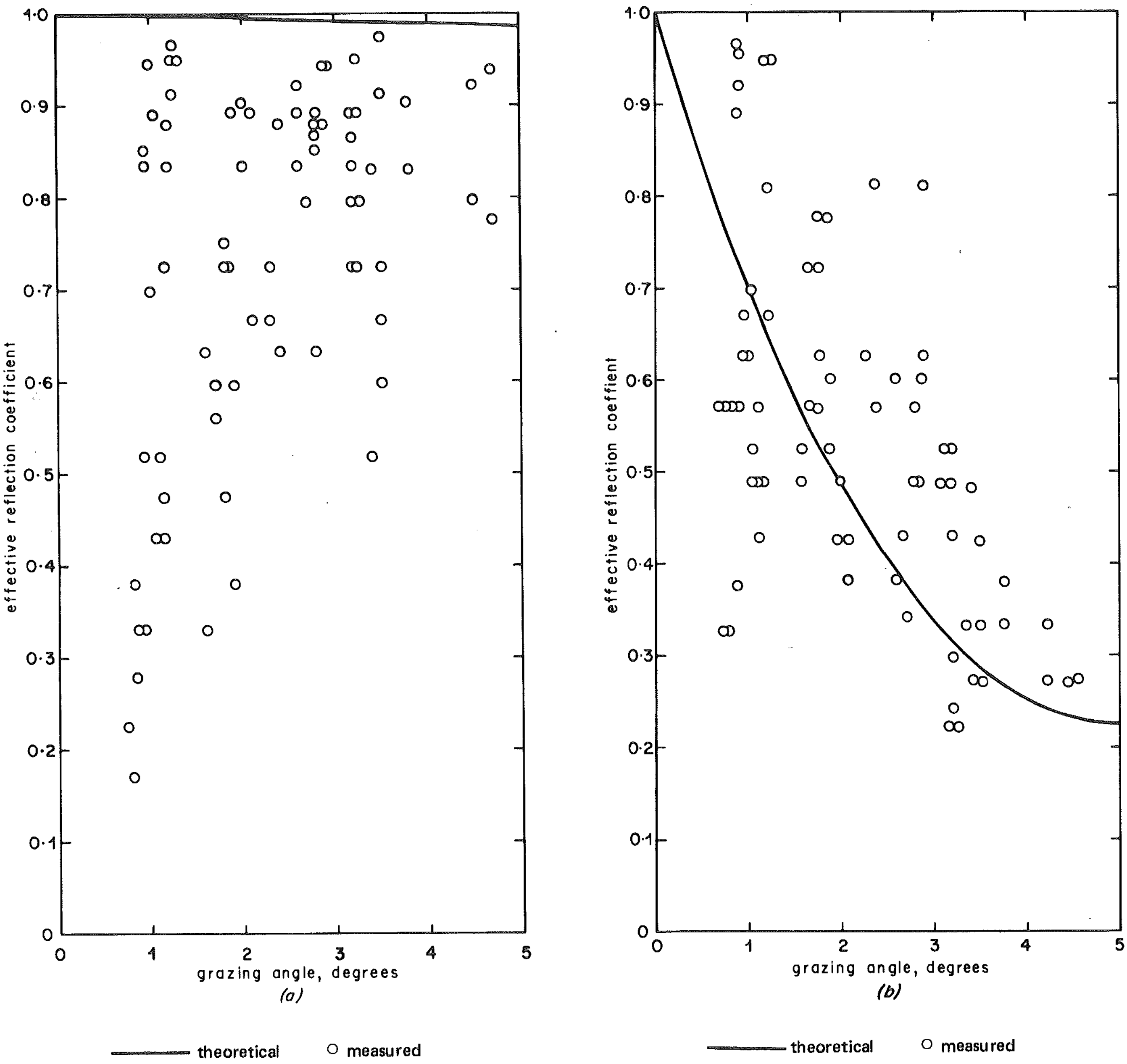

Fig. 2 - Effective reflection coefficients

(*a*) Horizontal polarisation (*b*) Vertical polarisation

wave is generally different from that required for maximum coupling with the direct wave, this implies a reduction in amplitude of the received signal in exchange for the rejection of the unwanted signal.

As the reflection coefficients vary with grazing angle, the system can only provide complete rejection of the reflected wave at a specific grazing angle. It will be shown later that useful suppression of the reflected wave may be obtained at grazing angles close to the nominal rejection angle.

The Appendix gives further details of theoretical aspects of this system.

3.2. Application to u.h.f. transmissions on short oversea paths

The principle described above can be applied to u.h.f. transmissions on short oversea paths to minimise fading due to sea reflections. The receiving aerial must respond to both h.p. and v.p. components of the transmitted signal, and it is suggested that receiving aerials could be tilted at 45°, thus responding equally to h.p. and v.p. components.

Suppose it is required to reject components reflected from the sea at a grazing angle of 2° for a frequency of 756 MHz; the required h.p./v.p. amplitude ratio is 0·491 and the h.p. component is retarded in phase by 158·7°

relative to the v.p. component.* For a grazing angle of 2° the reflected wave is plane-polarised at 45° from vertical, and this may be rejected by a receiving aerial tilted at 135° from vertical. In this case, the amplitude of the direct wave is reduced by 8·8 dB compared with the amplitude of the direct wave for h.p. or v.p. transmissions. This loss is probably acceptable at most locations where the rejection of the sea-reflected components is required, because the most serious fading occurs at locations where the amplitude of the direct wave is close to the free-space value.

At locations where fading is not significant viewers could use vertical receiving aerials, which would increase the amplitude of the direct wave by 7·9 dB, compared with that obtained with an aerial tilted at 135°.

Fig. 3 shows the variation of apparent reflection coefficient with grazing angle; the apparent reflection coefficient is defined as the ratio of the amplitudes of the reflected and direct waves as observed on an aerial tilted to 135°. For comparison, the reflection coefficients for h.p. and v.p. are also shown in Fig. 3. It will be noted that for elliptical polarisation, designed for a rejection angle of 2°, the apparent reflection coefficient is less than that for h.p. or v.p. for grazing angles up to about 3°. For grazing angles above 3°, the reflection coefficient is less if a v.p. receiving aerial is used.

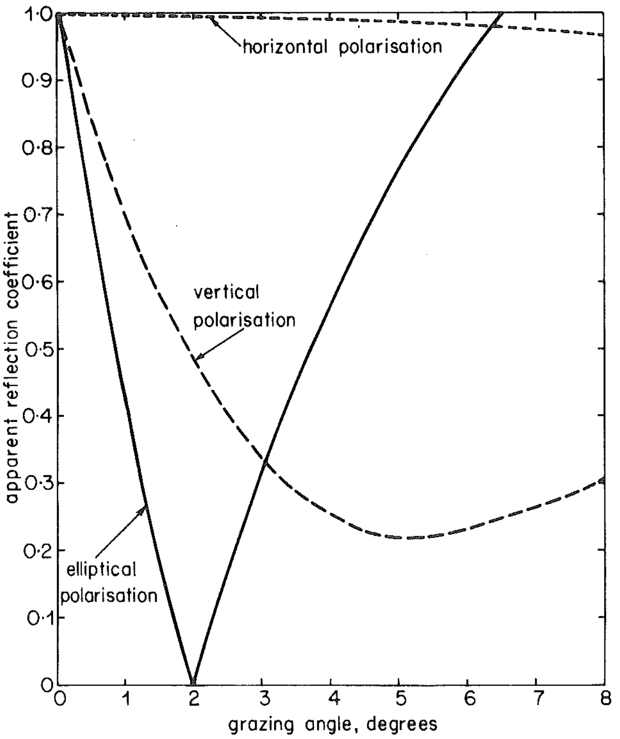

Fig. 3 - Variation of apparent reflection coefficient at 756 MHz of sea water for horizontal, vertical and elliptical polarisations
Rejection angle for elliptical polarisation: 2°

This example shows that reduction of fading may be obtained by using elliptical polarisation and tilted receiving aerials. It is possible to choose different rejection angles depending on the requirements, and calculations of the performance of this system have been made for a range of grazing angles and frequencies; some examples are shown in the Appendix.

It has been shown from theoretical considerations that elliptical polarisation could be useful on oversea paths. This treatment neglects certain factors which may cause deviations from the calculated performance. The tests described in Section 2 showed that ground reflected components were an important factor in determining the fading range. The amplitude of these ground reflected components may be reduced by the use of elliptical polarisation. Rapid fluctuations in amplitude of the received signal occur because of the roughness of the sea. For elliptical polarisation it is not known if these variations will be reduced or increased; this is dependent on the degree of correlation between the diffuse reflections for h.p. and v.p. Depolarisation of the h.p. and v.p. components is also expected to be important when the sea is rough.

4. Conclusions

The comparisons of horizontal and vertical polarisations indicate that if the Rosneath transmissions were horizontally polarised large parts of the service area would be severely affected by tidal fading. A change to vertical polarisation would alleviate the problem at most locations, but fading ranges (maximum/minimum) of more than 20 dB are still likely to occur at some locations. At locations where there were no significant ground reflections the theoretical values of fading range were confirmed. At other locations ground reflections had the effect of either increasing or decreasing the fading ranges. It should be noted that these results apply to the Rosneath service area and that the effects of ground reflections may be either more or less important in other service areas.

When the sea was rough, rapid variations in amplitude of the received signal were observed. The frequency of these fluctuations was about 0·3 Hz and their amplitudes were dependent on the roughness of the sea. These fluctuations may be more serious on short paths affected by tidal fading than the other types of picture degradation observed previously; i.e. delayed image interference and frequency selective fading.

It has been shown theoretically that elliptical polarisation can offer a significant improvement over both h.p. and v.p. on oversea paths affected by fading due to sea reflections. Tests of elliptical polarisation are in progress at Rosneath and the results will be published later.

5. References

1. TAPLIN, D.W, BELL, C.P. *and* LAVEN, P.A. 1970. Television reception over sea paths: the effect of the tide. BBC Research Department Report No. 1970/22.

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* The required h.p./v.p. amplitude and phase relationship is given by Equations (6) in the Appendix.

2. BEARD, C.I. 1961. Coherent and incoherent scattering of microwaves from the ocean. *IRE Trans. Antennas and Propag.*, 1961, **AP—9**, pp. 470 – 483.

3. BEARD, C.I. *and* KATZ, I. 1957. The dependence of microwave radio signal spectra on ocean roughness and wave spectra. *IRE Trans. Antennas and Propag.*, 1956, **AP—5**, pp. 183 – 191.

Appendix

Calculation of Amplitudes of Direct and Reflected Components for Elliptical Polarisation

Propagation on oversea paths within the horizon can be considered as the resultant of a direct and a sea-reflected component.* The amplitude of the received signal is:

$$E = E_o(1 + \rho e^{-j\phi}) \qquad (1)$$

where E_o is the free-space field strength
ρ is the complex reflection coefficient
ϕ is the phase delay due to the path difference between direct and reflected components.

For horizontal polarisation

$$E_h = E_{oh}(1 + \rho_h e^{-j\phi}) \qquad (2)$$

For vertical polarisation

$$E_v = E_{ov}(1 + \rho_v e^{-j\phi}) \qquad (3)$$

With a linearly polarised receiving aerial inclined at α° from the vertical, the amplitude of the received signal is

$$\begin{aligned} E\alpha &= E_v \cos\alpha + E_h \sin\alpha \\ &= \underbrace{E_{ov}\cos\alpha + E_{oh}\sin\alpha}_{\text{direct component}} + \underbrace{e^{-j\phi}(\rho_v E_{ov}\cos\alpha + \rho_h E_{oh}\sin\alpha)}_{\text{reflected component}} \qquad (4) \end{aligned}$$

If it is required to reject components reflected at a grazing angle ψ_o (i.e. where $\rho_v = \rho_{vo}$ and $\rho_h = \rho_{ho}$) with a receiving aerial tilted at α_o the h.p./v.p. ratio E_{oh}/E_{ov} must be chosen so that

$$\rho_{vo} E_{ov} \cos\alpha_o + \rho_{ho} E_{oh} \sin\alpha_o = 0 \qquad (5)$$

$$\therefore \quad \frac{E_{oh}}{E_{ov}} = \frac{-\rho_{vo}}{\rho_{ho}} \cot\alpha_o \qquad (6)$$

From (5) $$E_{oh} \sin\alpha_o = \frac{-\rho_{vo}}{\rho_{ho}} E_{ov} \cos\alpha_o \qquad (7)$$

Substituting (7) in (4), the amplitude of the received signal is

$$E\alpha_o = E_{ov} \cos\alpha_o \left[1 - \frac{\rho_{vo}}{\rho_{ho}} + e^{-j\phi}\left(\rho_v - \frac{\rho_h \rho_{vo}}{\rho_{ho}}\right)\right] \qquad (8)$$

The apparent reflection coefficient (ρa) is the ratio of the amplitudes of the reflected and direct components as observed on an aerial tilted at the required value of α_o, and

$$\rho a = \frac{\rho_v - \dfrac{\rho_h \rho_{vo}}{\rho_{ho}}}{1 - \dfrac{\rho_{vo}}{\rho_{ho}}} \qquad (9)$$

Fig. 4 shows the variation of apparent reflection coefficient ρa against grazing angle ψ at the surface of the sea for various values of rejection angle ψ_o.

If E_o is the free-space field strength due to a linearly polarised transmission of radiated power equal to the total radiated power of an elliptically polarised transmission

$$E_o^2 = E_{ov}^2 + E_{oh}^2 = E_{ov}^2\left(1 + \frac{E_{oh}^2}{E_{ov}^2}\right)$$

$$\therefore \quad \frac{E_{ov}^2}{E_o^2} = \frac{1}{1 + \dfrac{E_{oh}^2}{E_{ov}^2}} \text{ and } \frac{E_{ov}}{E_o} = \left(\frac{1}{1 + \dfrac{E_{oh}^2}{E_{ov}^2}}\right)^{1/2} \qquad (10)$$

From (8) the amplitude of the direct component, E_d, as observed with a receiving aerial tilted at α_o is given by

$$E_d = E_{ov} \cos\alpha_o \left(1 - \frac{\rho_{vo}}{\rho_{ho}}\right)$$

$$\frac{E_d}{E_o} = \frac{E_d}{E_{ov}} \times \frac{E_{ov}}{E_o} = \cos\alpha_o \left(1 - \frac{\rho_{vo}}{\rho_{ho}}\right)\left(\frac{1}{1 + \dfrac{E_{oh}^2}{E_{ov}^2}}\right)^{1/2} \qquad (11)$$

$$= \cos\alpha_o \left(1 - \frac{\rho_{vo}}{\rho_{ho}}\right)\left(\frac{1}{1 + \dfrac{\rho_{vo}^2}{\rho_{ho}^2} \cot^2\alpha_o}\right)^{1/2} \qquad (12)$$

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* All the examples of use of elliptical polarisation given in this Appendix relate to the rejection of sea-reflected components at a frequency of 756 MHz. It is assumed that for sea water $\epsilon r = 80$ and $\sigma = 4$ S/m.

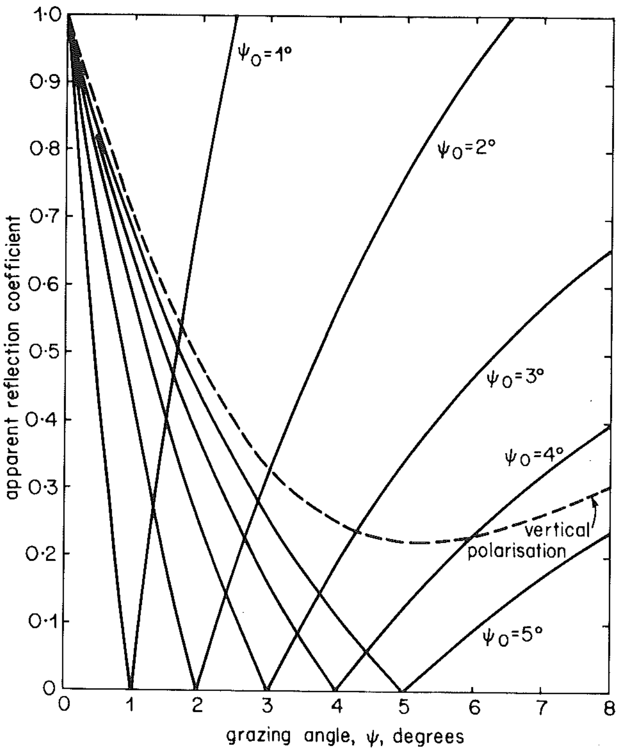

Fig. 4 - Elliptical polarisation: variation of apparent reflection coefficient at 756 MHz of sea water with grazing angle (ψ) for various values of rejection angle (ψ_o)

From (6) it will be noted that to reject the reflected component of a v.p. transmission the receiving aerial must be horizontally polarised (α_o = 90°), and that for h.p. transmissions the required value of α_o is 0° (v.p.). Equation (12) shows that when α_o = 0° or 90° the amplitude of the direct component E_d is zero, this implies that a vertical or horizontal receiving aerial would reject both direct and reflected components, as there is no change in polarisation after reflection for v.p. or h.p. signals.

From (11)

$$\frac{E_d}{E_o} = \cos\alpha_o\left(1+\frac{E_{oh}}{E_{ov}}\tan\alpha_o\right)\left(\frac{1}{1+\frac{E_{oh}^2}{E_{ov}^2}}\right)^{1/2} \qquad (13)$$

$$= \frac{\cos\alpha_o + \frac{E_{oh}}{E_{ov}}\sin\alpha_o}{\left(1+\frac{E_{oh}^2}{E_{ov}^2}\right)^{1/2}}$$

E_d/E_o has a maximum value when $\frac{d(E_d/E_o)}{d\alpha} = 0$

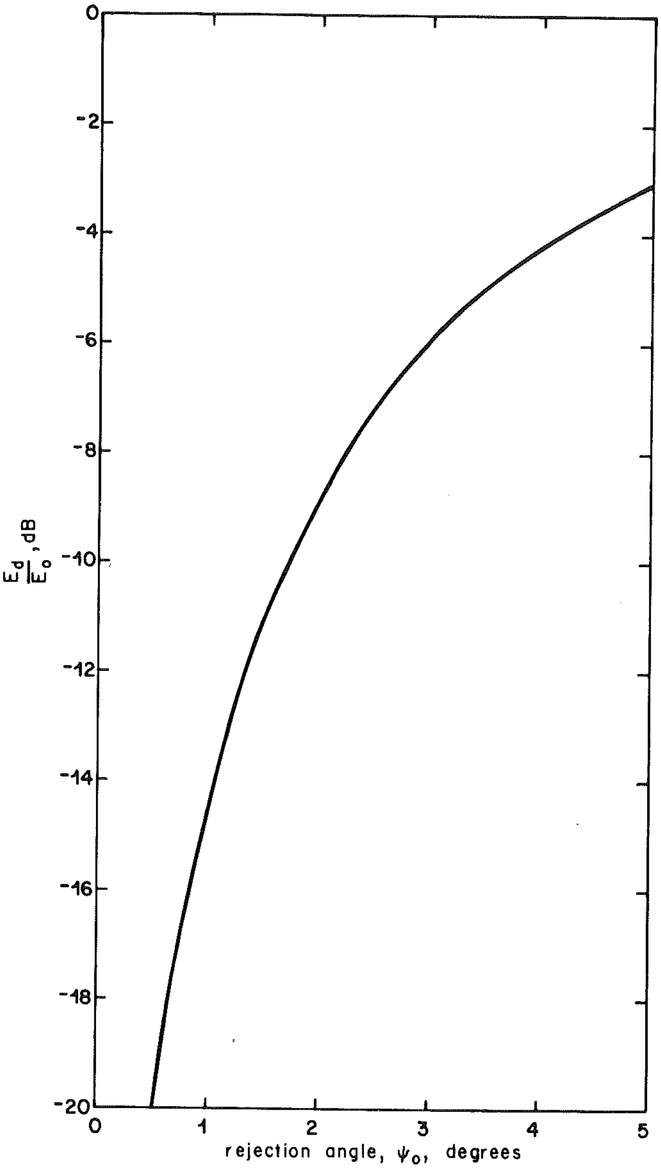

Fig. 5 - Elliptical polarisation: variation of E_d/E_o with rejection angle ψ_o where E_d is the free-space field strength of an elliptically-polarised transmission as observed with a receiving angle tilted at α_o = 135°

E_o is the free-space field strength of a linearly polarised transmission of radiated power equal to the total radiated power of the elliptically-polarised transmission

$$\frac{d\frac{E_d}{E_o}}{d\alpha} = \frac{-\sin\alpha_o + \frac{E_{oh}}{E_{ov}}\cos\alpha_o}{\left(1+\frac{E_{oh}^2}{E_{ov}^2}\right)^{1/2}} = 0 \quad \text{i.e. when } \frac{E_{oh}}{E_{ov}} = \tan\alpha_o \qquad (14)$$

It will be noted that E_d/E_o has a maximum value when E_{oh}/E_{ov} = $\tan\alpha_o$ and this implies that the optimum value for α_o occurs when $\tan^2\alpha_o = \rho_{vo}/\rho_{ho}$.

For use in a broadcasting system with its requirement for a simple aerial installation, the value of α_o = 135° is proposed. The change in amplitude of the direct component E_d for $\alpha_0 = 135^\circ$ compared with the optimum value is generally small; for the example given in Section 3.2 E_d/E_0 is −8·8 dB for $\alpha_0 = 135^\circ$ compared with the maximum value for E_d/E_0 of −8·3 dB when $\alpha_0 = 145^\circ$. Fig. 5 shows the variation of E_d/E_0 with $\alpha_0 = 135^\circ$ for values of ψ between 0·5° and 5°.

It should be noted that if a phase reversal of one component occurs, the value of α_0 changes from 135° to 45°. A phase reversal could be caused by physical inversion of a radiating element and it would be necessary to resolve this ambiguity by measuring the radiated h.p./v.p. amplitude and phase relationships.

Fig. 6 shows the variation of amplitude of the direct and reflected components against receiving aerial tilt (α) for $\psi_0 = 2{\cdot}5$ and $\alpha_0 = 135^\circ$. Fig. 7 shows the variation of apparent reflection coefficient against α for the same conditions as Fig. 6. It will be noted that for $\psi \neq \psi_0$, the minimum apparent reflection coefficient occurs at angles other than α_0. For example, if $\psi = 4^\circ$ the value of the apparent reflection coefficient is 0·16 at $\alpha = 155^\circ$ compared with 0·35 at $\alpha = 135^\circ$; a further advantage obtained by using $\alpha = 155^\circ$ is an increase of 4·1 dB in the amplitude of the direct component. For broadcasting purposes, viewers could not be expected to tilt their receiving aerials to the optimum angle for rejection of sea-reflected components, but for more specialised purposes such as re-broadcast links the use of tilted receiving aerials at angles other than α_0 could be advantageous.

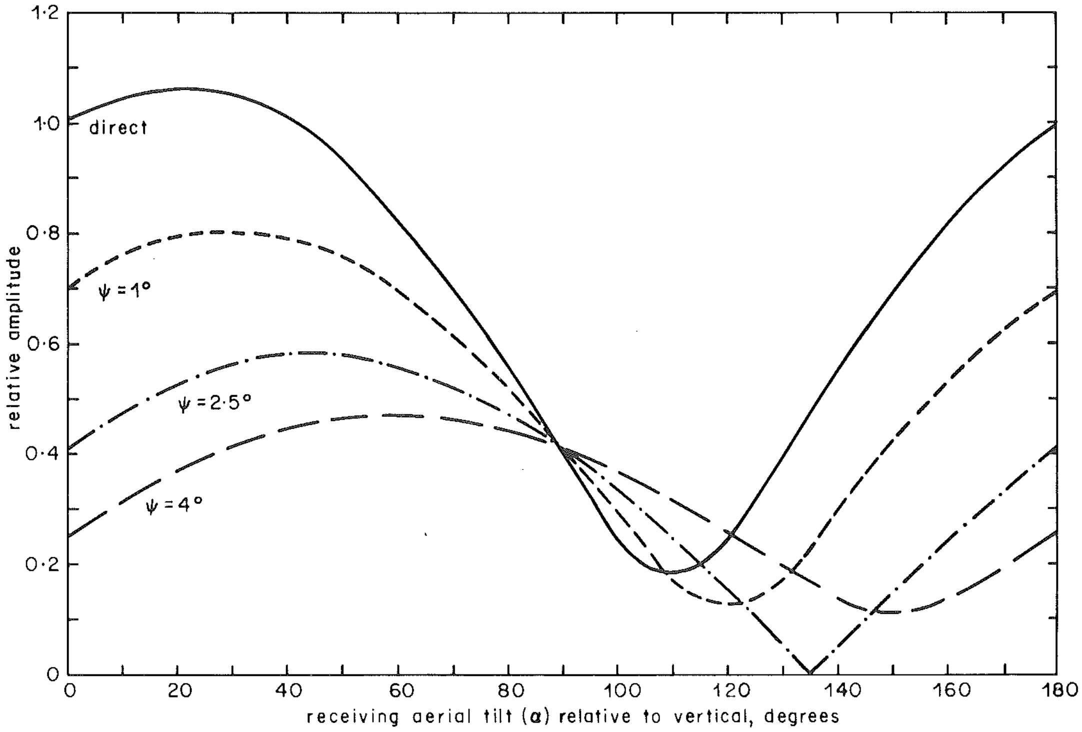

Fig. 6 - Elliptical polarisation: variation of amplitudes of direct and sea-reflected components with receiving aerial tilt (α) relative to vertical for various values of grazing angle (ψ)

Rejection angle (ψ_0) = 2·5°

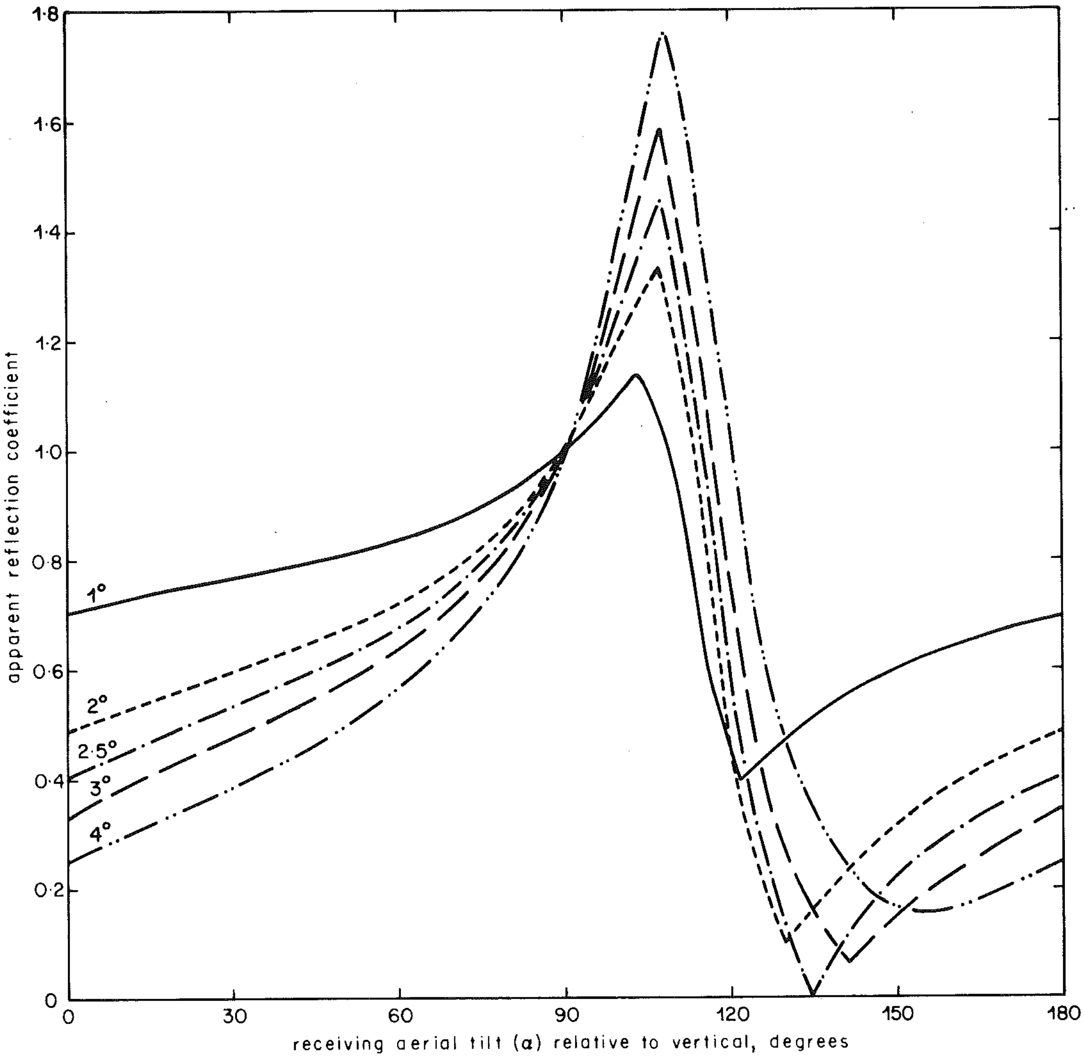

Fig. 7 - Elliptical polarisation: variation of apparent reflection coefficient of sea water with receiving aerial tilt (α) relative to vertical for various values of grazing angle (ψ)

Rejection angle (ψ_0) : 2·5°

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